United States
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Forest Health
Protection

Davis, CA

# Canopy Penetration in Almond Orchards

## Part 1:

## Efficiency of Deposition Within the Canopy

Hennigan almond orchard, Chico, CA 1994

FPM 96-3
November 1995

Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

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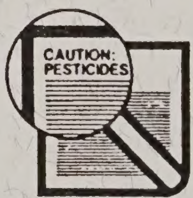
**NOTE:** Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.



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# CANOPY PENETRATION IN ALMOND ORCHARDS

## PART 1:

## EFFICIENCY OF DEPOSITION WITHIN THE CANOPY

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# Foreword

The USDA Forest Service (Forest Pest Management staff) and its cooperators, conducted studies in an almond orchard at the Hennigan almond orchard, Chico, California, during 1985 and 1994. The purpose of the studies was to characterize the penetration and deposition of aerial sprays into deciduous tree canopies. The replicated studies provided additional opportunities to evaluate sampling techniques, drift and environmental fate; to validate the FSCBG aerial spray dispersion model;. and to compare biological response to dose deposition. Orchards, with their relative uniformity of canopy structure and density, are ideal for conduct of such studies. John W. Barry, USDA Forest Service, designed and conducted the studies, and Milton E. Teske and Alina Z. MacNichol, Continuum Dynamics, Inc., performed the data analyses. The results are reported in a three-part report series as follows:

1. <u>Canopy Penetration in Almond Orchards</u>

   Part 1:

   Efficiency of Deposition within the Canopy
   USDA/FPM Report 96-3

2. <u>Canopy Penetration in Almond Orchards</u>

   Part 2:

   FSCBG Simulation of Drop Deposition and Downwind Drift
   USDA/FPM Report 96-4

3. <u>Canopy Penetration in Almond Orchards</u>

   Part 3:

   Biological Response within the Canopy
   USDA/FPM Report 96-5

The 1994 study was made possible by the outstanding cooperation of Bob Hennigan, Frank Zalom, Gary Kirfman, Joe Connell, Harold Thistle, and Pat Skyler; and similarly the 1985 study was made possible by Bob Hennigan, Bruce Grim, Jim Keetch, and Bob Ekblad.

J.W. Barry
Davis, CA
November 17, 1995

# Executive Summary

This paper evaluates drop deposition data from the tops and sides of beverage can samplers placed throughout a broadleaf (almond) canopy at three stages of foliage. Data from two field studies conducted at Hennigan Orchard in Chico, CA, in 1985 and 1994, were used to evaluate the amount and uniformity of coverage on the can samplers. A quantitative representation of coverage (called the Relative Index) is developed to describe the drop deposition on the samplers, and is then used to determine the spray deposition coverage of the various spray systems tested. Some measure of the uniformity of coverage of foliage is necessary to evaluate application quality and for improving methods of aerial application, since biological effectiveness is dependent on the level of deposition as well as the uniformity of deposition over the target (in this case, can samplers). This paper evaluates the overall performance of two types of spray systems (helicopter with nozzles and fixed-wing aircraft with Micronair atomizers) in terms of delivering spray on target at different canopy elevations. Top-of-can deposition data comparisons are also discussed. The principal conclusions reached by this report are:

1. The Relative Index formula developed herein for assessing drop recoveries on sides of beverage cans does a good job of correlating data from all trials at Hennigan Orchard.

2. The placement of beverage can samplers throughout the orchard in both field studies gave good representations of the effects of spraying the canopy.

3. The helicopter spray system applications (hydraulic nozzles) show greater uniformity of deposit on the sides of the beverage cans than the fixed-wing aircraft system applications (rotary atomizers) .

4. The Micronair atomizers spraying ULV produce less coverage on the sides and tops of the can samplers at all elevations in the canopy than the other, higher volume, spray systems tested.

5. Although the Micronairs spraying ULV show high variability in measured coverage on the sides of the beverage can samplers, they produce similar average coverage on the tops and sides of the samplers. The hydraulic nozzle systems tested show much higher average levels of deposition on the tops of the beverage cans than on the sides.

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# 1. Introduction

Pesticides are applied by aircraft to tree and crop canopies to control forest and agricultural pests. To determine the amount of coverage and spray deposit on foliage and vegetative elements, spray penetration through the canopy must be measured and evaluated (Barry, 1993). In the case of aerial spraying of biopesticides, for example, managers are interested in the amount of deposit and coverage necessary to ensure insect control throughout the canopy. Insect control depends not only on the amount of material deposited on a vegetative element, but also on the uniformity of coverage over the surface of that element. Thus, a 100% effective aerial application of a biopesticide into the canopy would uniformly cover all of the foliage with a level of spray that gives close to 100% insect mortality throughout the entire canopy. Developing a methodology to assess the amount, uniformity and biological effectiveness of spray deposition in a broadleaf canopy is essential to evaluate the quality of different types of aerial application in orchards (Roltsch et al., 1994).

The purpose of this report is to assess the uniformity of coverage and absolute level of drop deposition within a broadleaf canopy using data from two different field studies conducted at the Hennigan Almond Orchard, Chico, CA. Although the two studies were done at different times of the year and were conducted nine years apart, their canopy characteristics are very similar and represent three stages of flower and foliage (popcorn, blossom petal fall and full leaf stage).

In both field studies beverage can samplers were used to collect spray deposits vertically within the canopy. The USDA Forest Service (FS) has long been using beverage cans wrapped in Kromekote paper to assess relative deposition at different elevations in the canopy and uniformity of deposition on a three-dimensional surface (Barry et al., 1984). This type of sampler is easily available and inexpensive, and provides sufficient surface in the horizontal and vertical planes for wrapping Kromekote (Barry, Newton and Ekblad, 1988). The almond orchard studies discussed here provide replicated data from the tops and sides of can samplers.

Data from the sides of the can samplers are of particular interest because they indicate the uniformity of coverage at specific locations in the canopy. The aim of an effective aerial spray application is to place a desired level of spray material, containing an active ingredient, as evenly as possible throughout the canopy. Each of the field studies provides replicated sets of drop coverage data at specific locations in the canopy. Taken together, the trials provide coverage data within and beneath the canopy at various stages of flower and foliage, so that an assessment of the relative penetration of spray material at specific elevations from the top of the canopy to the ground can be made for each tree stage.

The number of drops deposited on foliage at different levels in the canopy depends on spray penetration. Penetration is dependent not only on canopy characteristics, but also physical properties and the drop size distribution of the spray material, and air turbulence and wind speed within the canopy. The two sets of Hennigan Orchard field studies were conducted with a variety of aircraft and spray systems, allowing also for comparison of the

relative effectiveness of fixed-wing aircraft versus helicopter-based spray systems at high, low and ultra low volume applications.

It is important to distinguish between two aspects of "effectiveness" of spray application throughout the canopy: the coverage effectiveness of the application, which pertains to uniformity of spray deposition on a target element (in this case, a beverage can sampler); and the biological effectiveness of the application, which pertains to pest control, and is achieved at a specific level of deposition all over the target. An attempt to quantify the overall effectiveness of spray application must address both coverage and biological effectiveness. Coverage effectiveness is found from drop data on target elements while biological effectiveness is either assumed or determined in the field or laboratory. Biological effectiveness is a measure of insect mortality and is therefore independent of field test conditions.

This report first summarizes the field studies conducted at Hennigan Orchard, then presents a statistical representation of overall effectiveness through a Relative Index (RI). This Index is demonstrated to be useful to the interpretation of, and test-to-test comparison of, beverage can field data. Finally, observations and conclusions based on RI are provided.

# 2. Field Studies Summary

## 2.1 Scope of the Field Studies

This report uses data from two field studies conducted at Hennigan Almond Orchard in Chico, CA.

In June and July of 1985, the FS conducted spray trials at Hennigan Orchard as part of Program WIND (Winds In Nonuniform Domains). Field test data from these trials will be referred to as the WIND 85 data. Program WIND was a cooperative study sponsored by the FS, the US Army Atmospheric Sciences Laboratory, and the US Army Dugway Proving Ground, of which the Hennigan Orchard trials were a very small part. One objective of the program was to obtain data describing the concentration and deposition of airborne materials over and within forests and complex terrain. To this end, can samplers were placed at 32 locations within the orchard canopy, each location having cans at four heights. The spray material used was water with additives and dye.

Three sets of trials (called Phases A, B and C) were flown with different spray systems. On the first day of testing, Phase A trials (A1 through A5) were flown with a fixed-wing aircraft and rotary atomizers spraying at low volume. On the second day of testing, Phase B trials (B1 through B5) and a single Phase C trial (C1) were flown with a Hiller 12E helicopter and hollow cone nozzles, spraying at low volume during Phase B and high volume during Phase C.

The WIND 85 trials provided an opportunity for the FS to study spray penetration in a relatively uniform broadleaf canopy. Since the can samplers were placed at four different heights, ranging from the bottom to the top of the canopy, the WIND 85 data can be used to judge relative penetration throughout the entire canopy of full-leaf stage broadleaf trees. The WIND 85 trials are described in detail in Newton, Barry and Ekblad (1988).

In 1994 another study was conducted at Hennigan Almond Orchard (Zalom et al., 1994). This study was a cooperative effort between grower Bob Hennigan, the University of California Extension, Entotech, Inc. and the FS, and will be referred to as Hennigan 94. The Hennigan 94 trials took place from January to March, and were designed to represent two stages of tree flower and foliage, popcorn (bloom expansion) and blossom petal fall. Since the objective of this study was to evaluate the biological effectiveness of the biopesticide *Bacillus thuringiensis* (Bt) in controlling peach twig borer, the spray material used was Biobit XL, a form of Bt produced by NOVO NORDISK (since this study NOVO NORDISK sold its biological insecticides to Abbott Laboratories).

There were four stages of aerial application: Phase A, a conventional high volume chemical treatment applied in January during tree dormancy; and Phases B, C and D, various tank mixes of Bt applied once in February when the foliage was in its popcorn stage and repeated in March when the foliage was in its blossom petal fall stage. Each phase of testing represented a type of application. Phase A, representing conventional treatment applied with a helicopter, provided a baseline for comparison of Bt treatments to the standard treatment methods; data from this phase are not used in this report. Phases B

and C represented low-volume and high volume (respectively) Bt treatments applied with a helicopter and CP nozzles; Phase D represented ultra low volume (ULV) Bt treatments applied with a fixed-wing airplane and rotary atomizers.

For the Hennigan 94 trials the orchard was divided into 20 plots, and the aircraft flew over four plots during each treatment phase (for replication). In each plot, can samplers were placed at ten locations in the canopy (all at mid-canopy height) and ten locations below the canopy nearly at ground-level (0.46 meters). Thus, there are data from forty mid-canopy samplers, and forty samplers below the canopy, for each phase of the study. Although there is no way to ascertain relative penetration at different heights within the canopy, penetration to mid-canopy and penetration through the canopy to ground-level can be evaluated.

The Hennigan 94 trials are detailed in the study in Zalom, et al. (1994).

## 2.2 Spray Site

As previously mentioned, both field studies were conducted at Hennigan Almond Orchard in Chico, CA. Orchard characteristics at the time of each of the field studies are given in Table 1. Although the exact portions of the orchard used in 1985 and 1994 differ, the entire orchard will be assumed to be relatively uniform during each growing season.

Figure 1 shows the location of the can samplers for each of the field studies. The WIND 85 trials were conducted over one portion of the orchard, with four trees designated as sample trees. Samplers were positioned on telescoping poles which reached to the top of the canopy. Two poles were placed adjacent to each sample tree, at the tree dripline. Can samplers were placed at four heights on each pole (3.0, 4.9, 6.4 and 8.2 meters).

The Hennigan 94 trials (in 1994) divided the orchard into 20 plots of various sizes, with each phase being conducted over four plots. The twelve plots which comprised Phases B through D ranged in size from 8.1 to 16.3 acres. In the center of each plot there were five adjacent sample trees. Two samplers were placed at mid-canopy height (4.6 meters), one on the east side of the tree and one on the west side. The samplers were on PVC pipes placed 1.2 meters inside the tree dripline. Two more samplers were placed approximately at ground level (0.46 meters), directly underneath the canopy samplers.

During the earlier WIND 85 trials, when the trees were in full leaf stage, adjacent branches were touching and the canopy was uniform (Barry, Newton and Ekblad, 1988). Thus, even though samplers were placed at the tree dripline, they can be assumed to be within the canopy. During the Hennigan 94 trials the canopy was not quite uniform, due to tree replacement on some rows and pruning, but can samplers were placed well within the dripline.

The beverage can samplers used in both field studies consisted of Kromekote cards wrapped on the sides of empty aluminum soft drink cans, with squares of Kromekote attached to the tops of the cans as well. The exact dimensions of the Kromekote cards covering the tops of the cans differed slightly for the studies: the WIND 85 can samplers had 36 square centimeters of card surface on top; the Hennigan 94 cans had 40 square

centimeters on top. Thus, there was 11% more surface area on the tops of the Hennigan 94 can samplers. The sides of the cans were completely wrapped, and covered the same area for both field studies.

Meteorological towers were located in the orchard during each field study, but these data are not addressed in this report, as we will be concentrating here on the card deposition alone. How the spray material got to the cards, including predicting its behavior, forms the subject of Part 2 of this report (MacNichol 1996).

## 2.3 Aircraft and Spray Systems

The aircraft and spray systems used in each phase of the WIND 85 study and the Hennigan 94 study are summarized in Table 2.

In both field studies the fixed-wing airplane flown was an Ag Cat, and the spray system used consisted of six Micronair rotary atomizers placed along the microfoil boom of the airplane. The helicopter flown in the WIND 85 trials was a Hiller 12E; its spray system consisted of 28 T-Jet, D2-45 hollow cone nozzles for Phase B and 28 T-Jet nozzles with mixed tips for Phase C. The Hennigan 94 trials used a Bell Jet Ranger 206 helicopter whose spray system consisted of CP plastic nozzles, 20 for Phase B and 60 for Phase C.

Flight speeds of the aircraft in the two field studies were similar. Release height above the mean canopy top was 3.0 meters in the WIND 85 trials and 1.5 meters in the Hennigan 94 trials. As previously mentioned, application rates during the trials varied from ULV (0.5 gal/acre for Phase D of Hennigan 94) to high volume (30 gal/acre for Phase C of Program WIND 85).

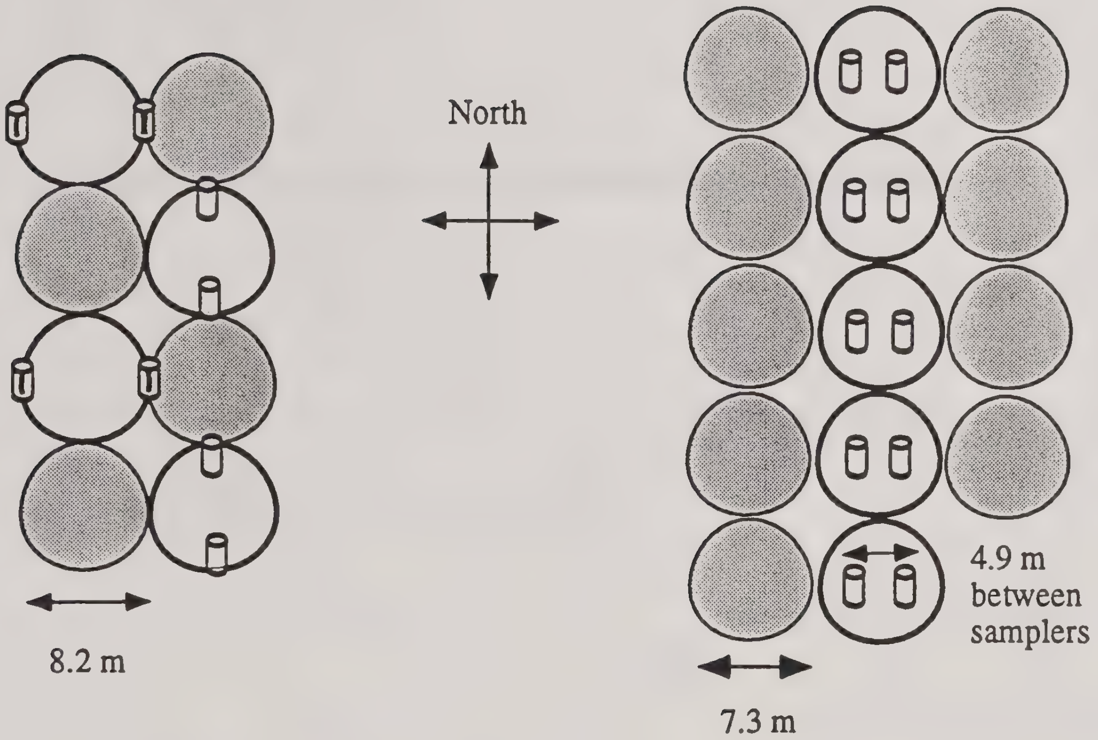
The material sprayed in the WIND 85 trials was water with Nalco-Trol, Rhodamine liquid dye and salt tracer manganese sulfate. The Hennigan 94 trials were designed to test the effectiveness of the pesticide Bt, so the material sprayed was Biobit XL, a form of Foray 48B, with blue, grape and black dyes mixed in for Phases B, C and D, respectively.

In both field studies, the spraying aircraft flew multiple passes over portions of the orchard that contained sample trees. During the WIND 85 trials, the tank mix was applied by swathing north-to-south or south-to-north over the entire length of six tree rows, in 9.1 meter swaths. Since the WIND 85 trees were spaced 8.2 meters apart center-to-center, the aircraft flew over the sample trees, but not directly over their centers. During the Hennigan 94 trials, the aircraft flew in 12.5 meter swaths, north-to-south or south-to-north, over all of the plots in a given phase (e.g.., plots 9, 10, 11, and 12 for Phase C). The Hennigan 94 trees were spaced 8.1 meters center-to-center; the aircraft in these trials did not fly directly over the sample trees in every plot either.

The WIND 85 trials were conducted between the hours of 5:41 AM and 9:25 AM, in mid-summer (June and July) The Hennigan 94 trials were conducted between 11:15 AM and 3:00 PM, in late February and early March.

## 2.4 Data Reduction Procedure

The beverage can samplers in both field studies were positioned the morning of the scheduled spray day and retrieved the same day, after spraying. The tops and sides of the samplers were then assessed for number and size of drop stains and spray volume. Sides of cans were assessed visually. Tops of cans were assessed using an image analyzer (the Quantimet analyzer for the WIND 85 trials). All data were processed through the Automatic Spot Counting and Sizing System - ASCAS - data reduction program (Teske 1992). Side-of-can data reduction will be discussed further in the next section, and top-of-can data reduction will be discussed in section 5.




Program WIND Almond Orchard, 1985:

- trees are 8.2 m. center-to center
- mean canopy height = 8.2 m.
- 4 sample trees in the orchard
- 2 poles placed adjacent to each tree, at the tree dripline, each pole with samplers at four heights, from bottom of canopy to top of canopy

Hennigan Almond Orchard, 1994:

- trees are 8.1 m. center-to center
- mean canopy height = 7.6 m.
- 5 sample trees in the center of each plot
- 4 samplers placed in each tree, two at 0.46 m and two at mid-canopy

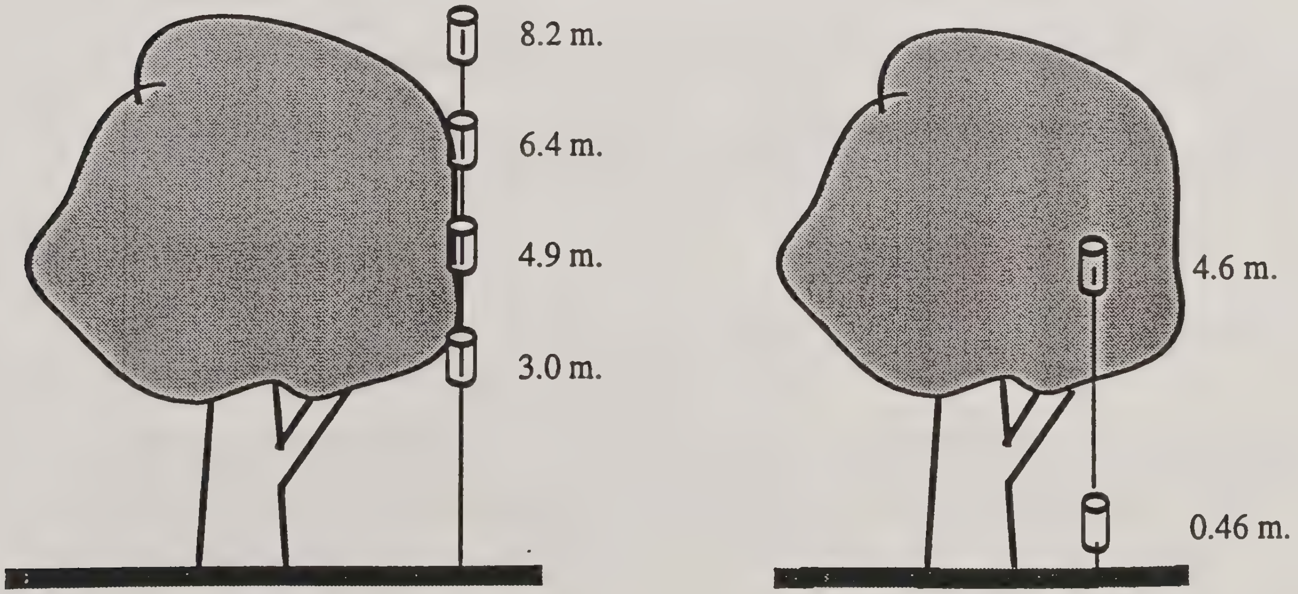



Figure 1: Placement of sample trees and beverage can samplers in Hennigan Almond Orchard for the WIND 85 study and the Hennigan 94 study.

Table 1: Hennigan Almond Orchard Characteristics, 1985 and 1994

| | WIND 85 (June-July 1985) | Hennigan 94 (Feb-Mar 1994) |
|---|---|---|
| Mean Canopy Height (m) | 8.2 | 7.6 |
| Tree Separation, center-to-center (m) | 8.2 | 8.1 |
| Stand Density | 60 stems/acre | 62 stems/acre |
| Tree Stage | Full Leaf | Popcorn (Feb)[1]<br>Blossom Petal Fall (Mar)[1] |
| Crown Diameter (m)[2] | 8.2 | 7.3 |

1. These are bloom stages; popcorn refers to bloom expansion.
2. Crown pruning likely accounts for smaller crowns from 1985 to 1994.

Table 2: Aircraft and Spray Systems for WIND 85 and Hennigan 94

| Test/ Phase | Plots/ Trials | Aircraft | Speed (m/sec) | Release Height[1] (m) | Nozzle or Atomizer Type/ Application Rate[2] |
|---|---|---|---|---|---|
| WIND 85 | | | | | |
| A | 1 - 5 | Ag Cat | 42.5 | 3.0 | Micronair Atomizers ...... 4.0 gal/acre |
| B | 1 - 5 | Hiller 12E | 11.2 | 3.0 | D2-45 T-Jet Nozzles ...... 4.0 gal/acre |
| C | 1 | Hiller 12E | 11.2 | 3.0 | T-Jet Nozzles ...... 30.0 gal/acre |
| Hennigan 94 | | | | | |
| B | 5 - 8 | Bell 206 | 13.4 | 1.52 | CP Nozzles ...... 5.0 gal/acre with 0.062 orifice |
| C | 9 - 12 | Bell 206 | 13.4 | 1.52 | CP Nozzles ...... 15.0 gal/acre with 0.062 orifice |
| D | 17 - 20 | Ag Cat | 49.2 | 1.52 | Micronair Atomizers with 55 degree blade angle ...... 0.5 gal/acre |

1. Release height above canopy. Mean canopy height for WIND 85 = 8.2 meters. Mean canopy height for Hennigan 94 = 7.6 meters.

2. The tank mix for WIND 85 was composed of a mixture of water, Nalco-Trol, Rhodamine liquid dye and salt tracer manganese sulfate. The formulation sprayed during Hennigan 94 was a form of Foray 48B, with different dyes used for each phase.

## 3. Relative Index

The number of drops on the sides of the beverage can samplers were assessed using the same method for both Hennigan studies. The sides of each can were unwrapped and evaluated as single Kromekote samplers, as described in detail in Zalom, et al. (1994).

Because spray is released in a preferred direction (which depends on the aircraft flight path and the prevailing wind over the test site), certain portions of each side sampler can be expected to be covered more than others. To distinguish the side of the sampler which received the most deposition from the side which received the least deposition, the side samplers were divided into four segments, with two segments encompassing that part where the greatest number of stains was located and two encompassing that part where the least number of stains were located. The side-of-can segments were then ranked in order of the number of drops measured in each, with $N_1$ representing the segment with the most drops and $N_4$ the segment with the fewest drops.

Side-of-can data from the WIND 85 trials were statistically analyzed by Newton, Barry and Ekblad (1988) using the procedure just described. The percentage of the card covered with stains was noted. The eight poles positioned around sample trees were assumed to represent eight replications of each sampler position (at 3.0, 4.9, 6.4 , and 8.2 meters) and each of the five trials flown in Phases A and B provided further replication at each height. Thus, all data may be averaged and normalized to the top of the canopy in order to assess relative penetration at the four elevations. Data from Phase C, which had only one trial, were treated in the same way. Side-of-can data from Hennigan 94 have not been analyzed prior to this report.

As previously discussed, to assess the overall effectiveness of deposition on the sides of the can samplers in these studies two steps are necessary:

1. Represent the coverage effectiveness based on the number of drops deposited in each segment of the can sampler.

2. Represent the biological effectiveness by a base drop count (in drops per square centimeter) that is assumed (or known) to provide 100% biological effectiveness over a segment of foliage.

The following empirical formula is proposed to evaluate overall effectiveness on each sampler, which will be called the Relative Index (RI):

$$RI = \sqrt{\frac{N_1 + N_2 + 3(N_3 + N_4)}{8\,N_B}}$$

where $N_1$ through $N_4$ refer to the number of drops measured in segments ranked 1 through 4, and $N_B$ is the base drop count, which depends on the type of pesticide being sprayed and the target pest. For the Bt formulation used in both Hennigan studies, the base drop count for peach twig borer is assumed to be 20 drops per square centimeter (J.W. Barry memorandum, February 1995). Because segments covered with more than 20 drops are therefore assumed to be at a level of 100% biological effectiveness, whenever

$N_1, N_2, N_3$, or $N_4$ are greater than $N_B$, they are set equal to $N_B$. In other words, oversaturation of the foliage will produce no more than 100% overall effectiveness, or an RI = 1.0. Thus, it may be seen that RI will obtain values between 0 and 1.0 for all side-of-can data evaluated.

Table 3 gives the RI values generated from various combinations of segment drop counts. As noted, when the drop count on all the segments is greater than or equal to $N_B$, in this case 20 drops, RI = 1.0 (examples 1 and 2). When very few drops are counted on all segments, the RI approaches zero (example 7). Nearly uniform coverage gives a higher RI than 100% coverage over half the can and very small coverage over the other half (examples 3 and 4 in Table 3). Since the object of spraying is to get as complete coverage as possible on the target elements, the RI calculation favors uniformity over absolute drop measurement in any given segment. When the drop count is small over the entire sampler, the RI is higher when drops are uniformly distributed in several segments than when all drops are in one segment (examples 5 and 6, total drop count in both examples = 10). In fact, example 5 shows that it is possible to have an RI of greater than 0.30 with small levels of deposition all around the sampler.

Actual field data are shown below the seven example calculations. Note that field data from Hennigan 94 are named by beverage can position around the sample tree: "ce" denotes canopy east (4.6 meters elevation, east of the sample tree centerline); "cw" denotes canopy west (4.6 meters elevation, west of the sample tree centerline); "ge" denotes ground east (0.46 meters elevation, east of the sample tree centerline); and "gw" denotes ground west (0.46 meters elevation, west of the sample tree centerline).

As expected, the highest RI values are for cans which have high drop counts on all four segments. If only one segment of the sampler has $N_B$ drops, the RI for the sampler is 0.35. Thus, when RI is less than 0.35 there is no segment on the sampler which shows 100% (or greater) biological effectiveness. For most cases where RI is at or above 0.40, there is 50% or greater biological effectiveness in one or more segments, or there is uniform coverage of at least one quarter $N_B$ over the entire sampler. Thus, RI appears to accurately represent overall effectiveness on can sampler sides, combining both coverage and biological effectiveness into one expression.

Now that a measure of the overall effectiveness of the application at each sampler position has been established, the side-of-can data from WIND 85 and Hennigan 94 can be evaluated.

Table 3: Examples of Relative Index Calculations

| Example | $N_1$ | $N_2$ | $N_3$ | $N_4$ | RI |
|---|---|---|---|---|---|
| 1 | 20 | 20 | 20 | 20 | 1.0 |
| 2 | 35 | 35 | 24 | 23 | 1.0 |
| 3 | 10 | 10 | 10 | 10 | 0.70 |
| 4 | 20 | 20 | 0 | 0 | 0.50 |
| 5 | 4 | 3 | 2 | 1 | 0.32 |
| 6 | 10 | 0 | 0 | 0 | 0.25 |
| 7 | 1 | 0 | 0 | 0 | 0.08 |

| Trial and Sampler Location | Side of Can Segments: 1 | 2 | 3 | 4 | RI |
|---|---|---|---|---|---|
| WIND 85 Trial A1 Pole 1, 3.0m | 11 | 11 | 3 | 0 | 0.44 |
| WIND 85 Trial A1 Pole 1, 8.2m | 200 | 117 | 34 | 1 | 0.80 |
| WIND 85 Trial A1 Pole 3, 3.0m | 4 | 4 | 2 | 2 | 0.35 |
| WIND 85 Trial A1 Pole 5, 3.0m | 8 | 3 | 2 | 0 | 0.33 |
| Hennigan 94[1] Plot 5, Tree 1 ce | 48 | 47 | 4 | 1 | 0.59 |
| Hennigan 94[1] Plot 5, Tree 1 ge | 35 | 6 | 3 | 0 | 0.47 |
| Hennigan 94[1] Plot 5, Tree 4 ce | 43 | 26 | 18 | 11 | 0.89 |
| Hennigan 94[1] Plot 6, Tree 3 ge | 13 | 11 | 0 | 0 | 0.39 |
| Hennigan 94[1] Plot 18, Tree 2 ce | 4 | 2 | 1 | 0 | 0.24 |
| Hennigan 94[1] Plot 19, Tree 2 gw | 3 | 1 | 0 | 0 | 0.16 |

1. For Hennigan 94, "ce", "cw", "ge", and "gw" denote position of the can sampler around the sample tree: canopy east (ce), canopy west (cw), ground east (ge), and ground west (gw).

## 4. Statistical Evaluation of Side-of-Can Data

The first step in evaluating the side-of-can data from the two Hennigan field studies is to evaluate the RI calculations in terms of repeatability of data. At each tree stage, trials were conducted over similar canopies over similar periods of time during the day, and meteorological conditions inside the canopy can be assumed to be uniform from sampler location to sampler location at each elevation. Thus, the samplers around each tree are assumed to experience similar canopy effects at each elevation regardless of their position with respect to the tree centerline (east of the centerline versus west of the centerline), or the aircraft flight lines.

As previously discussed, there are 32 replications of data at each height for each phase of WIND 85, giving a total of 160 replications for Phases A and B and 32 replications for Phase C over the full leaf stage canopy. There are 40 replications of ground-level data and 40 replications of mid-canopy data for each phase of Hennigan 94, giving a total of 80 replications per phase over the popcorn stage and blossom petal fall stage canopies.

To give a general idea of the range and frequency of occurrence of RI values calculated for all samplers in the Hennigan 94 trials, a histogram of RI for all 480 can samplers was plotted (Figure 2). This plot incorporates RI values calculated for three different types of application at two tree stages. Note that there are three distinct peaks in the frequency of occurrence for RI. Figures 3a, b, and c show histograms for each phase of treatment during the popcorn stage (February 22), and indicate that each peak in the overall frequency distribution corresponds to a change in phase, or application method.

Since the phases represent different rates of application, all data from Hennigan 94 were normalized to the Phase B flow rate of 5.0 gal/acre (low volume application). RI values at each sampler position were recalculated with a normalized value of $N_B$. The resulting histogram for all samplers in Hennigan 94 is given in Figure 4. The corresponding normalized histogram for all samplers in Phases A and B of the WIND 85 study is given in Figure 5 (normalized RI values for Phase C are all very close to 1.0 due to the very high volume of spray).

Normalized histograms of each phase of application in Hennigan 94 indicate much more scatter in the RI calculations for Phase D (Micronair atomizers at ULV). Very small numbers of drops were deposited on the sides of cans in this phase, and many segments had no drops at all, resulting in 25 (out of 80) samplers with an RI of zero. A histogram of the normalized RI from Phases B and C (low and high volume application with a helicopter), at both tree stages, is shown in Figure 6a. This figure shows a normal distribution, with mean of 0.57 and median of 0.57. Such a distribution indicates that the Hennigan 94 data can be taken as a statistically random sample over the entire orchard canopy (MacNichol 1994), and that normalizing $N_B$ does collapse the calculation of Relative Index for different flow rates. Since this histogram includes data from samplers placed on either side (east-west) of the sample trees, RI at the two elevations represented (ground level and mid-canopy) would appear to be independent of relative location with respect to tree centerline. Furthermore, the overall effectiveness as measured by RI appears

to be independent of tree phase for the spray system used in these two phases of the Hennigan 94 study; this development will be discussed further later.

The normalized histogram for WIND 85 Phase B is shown in Figure 6b. These data represent application by a helicopter with a similar spray system to that of Hennigan 94 Phases B and C. The canopy is in full leaf stage. The mean RI is 0.81 and the median is 0.83. Note that there are four elevations within the canopy represented by these data.

All RI values referred to in the remainder of this section are normalized as described above.

Figure 7 and Table 4 show quantitative assessments of the differences in the normalized RI data for the WIND 85 and Hennigan 94 studies. In Figure 7, the data are presented as a bar chart comparing average normalized RI values by type of spray system. Note that the average RI for WIND 85 Phase C (nozzles spraying at high volume) is nearly 1.0, even with an attempt to normalize the flow rate. The foliage was oversaturated in this phase of the WIND 85 study, resulting in absolute drop counts (in drops per square centimeter) of well over 100 for most of the side-of-can segments assessed. Without normalization, every sampler in this phase has an RI of 1.0.

In Table 4, the average normalized RI and the relative standard deviation (RSD) of the average are shown by type of spray system. RSD is a measure of the relative scatter in the data. RSD $< 0.1$ indicates very little scatter in the data, while RSD $> 0.5$ indicates a large amount of scatter. Note that the RSD for helicopters spraying with nozzles is approximately 0.2, and is very similar for WIND 85 and Hennigan 94 even though different nozzles and aircraft were used in the two tests. There also seems to be little difference in the scatter of the data due to difference in tree stage.

The RSD for fixed-wing aircraft spraying with Micronair atomizers is much higher than that for a rotary-wing spray system. The RSD for RI calculations for Hennigan 94 Phase D (ULV application with Micronairs) is over 0.5. Hennigan Phase D was the treatment phase which showed very little drop deposition on the sides of the can samplers (see discussion above). Nevertheless, the values of normalized RI and RSD for popcorn and petal phase are similar, and indicate that ULV spraying with Micronair atomizers gives much less effective coverage throughout the canopy than spraying at low and high volumes with helicopters. WIND 85 Phase A was a low volume application with Micronair atomizers; the overall level of drop deposition is higher, and RSD is lower than for the Hennigan 94 Micronair application. This phase of WIND 85 was conducted much earlier in the morning than the other trials examined here, when spray would be more likely to penetrate the canopy.

WIND 85 Phases A and B provide the most direct comparison between a helicopter spraying with hydraulic nozzles and a fixed-wing aircraft spraying with Micronairs. The application rate in both Phases is 4.0 gal/acre (low volume), and trees are in full leaf stage. The average normalized RI and is 36% higher for the helicopter spray system, and data from that spray system show 36% lower RSD than data for the fixed-wing spray system. For this growth stage, the helicopter spray system clearly deposits material more effectively than the fixed-wing system.

Both the WIND 85 data and the Hennigan 94 data can be evaluated at different elevations in the canopy. Because the canopy height differed slightly in the two field studies, normalized elevations will be used in all comparisons. Data are available at the following normalized elevations: 0.37, 0.59, 0.78 and 1.0 (the canopy top) for WIND 85; and 0.06 and 0.60 for Hennigan 94.

Table 5 shows the normalized average RI and RSD for the side-of-can data, by tree stage and elevation, for the two types of spray system. Note that the RSDs for all RI calculations done with data from the helicopter spray systems are similar, and are in the neighborhood of 0.2. There is considerably more variation in the RI calculations for data from the fixed-wing spray system, as is to be expected from Table 4. In their analysis of data from the Charter Almond Orchard trials flown in Feb-March of 1992 (with Micronairs spraying ULV from an Ag Cat), Roltsch et al. (1994) also found high variability of sampler deposition at specific vertical strata within the canopy.

Although normalized average RI values calculated for data from the helicopter spray system are lower than those calculated for data from the fixed-wing spray system, RI shows the same trend with elevation for each type of application. During the popcorn and blossom petal fall stages, data are only available at mid-canopy and at ground level. Average RI shows little change between these two elevations, regardless of the aircraft and spray system. Considering the amount of variability in these averages, the overall effectiveness from mid-canopy level to the ground seems to be the same. There also appears to be no significant change in overall effectiveness at these elevations between the popcorn stage and the blossom petal fall stage.

Figure 8 shows the average normalized RI by elevation in the full leaf stage canopy, for the two spray systems in WIND 85 (helicopter with hydraulic nozzles at low and high volume; fixed wing aircraft with rotary atomizers at ULV). The average normalized RI is significantly lower at the bottom of the canopy, indicating that coverage gets worse as the spray passes through the full leaf canopy. For the helicopter spray system, the difference in RI between the top of the canopy and the mid-canopy elevation is minimal; from mid-canopy to the bottom of the canopy, RI decreases by 30% during low volume application and 16% during high volume application. For the fixed-wing spray system the RI decreases progressively, and RI at the bottom of the canopy is only about 50% of the RI at the top. This trend agrees with the conclusions of Roltsch et al. (1994), who found that droplet densities from a fixed-wing, ULV, Bt applicator were observed to be greater in upper versus mid-canopy regions.

The RSD in RI calculations during the full leaf phase appears to decrease with canopy elevation. This trend is also apparent in the fixed-wing spray system data: there is more scatter in the relative index of coverage at the bottom of the canopy than at the top. The variability in RI calculations for popcorn and blossom petal fall stages appears to be uniform from mid-canopy to the ground. It is worth noting that, while the normalized overall effectiveness at the mid-canopy level is similar for the two blooming stages, and significantly higher for the full leaf canopy, the overall effectiveness at the ground/bottom of canopy level is essentially the same for all three tree stages (WIND 85 Phase C is a very high volume application in which the foliage was saturated to dripping). At the mid-canopy level, the blooming stages may result in more obstruction in the canopy than when leaves are full, but blooms are absent. Thus, although the same uniformity of coverage is

seen below the canopy in each tree stage, there is less uniformity of coverage within the canopy during the blooming stages than there is when the canopy itself is composed of more uniform elements.

The decrease in RI from top to bottom of a full leaf canopy is probably a natural result of the spray passing through the foliage (Barry, 1984). The largest drops impact right away and with good uniformity of coverage. As spray penetrates the foliage, the predominant drop size becomes smaller, and many more drops evade the sampler sides: small drops have a lower impaction efficiency than large drops (May and Clifford, 1967). The overall impaction efficiency of the remaining drops will decrease as the spray continues to penetrate the canopy, and overall effectiveness will decrease. Thus, fewer drops will settle on the foliage at the bottom of the canopy than on the foliage at the top. This trend can be seen in RI values for WIND 85, for which there are data throughout the canopy. Unfortunately, there are not similar data for Hennigan 94 (the only canopy elevation for which data are available is mid-canopy).

In the case of the Micronair atomizers, the spray produced many smaller drops to begin with. Given similar levels of turbulence within the canopy, the predominance of larger drops in the spray from the helicopter hydraulic nozzles should result in a greater number of drops impacting on the can samplers at any elevation in the canopy during the helicopter phases of the field studies.

It is important to note the difference in spray produced by hydraulic nozzles and rotary atomizers. The Micronair atomizers produce a fine spray with a much greater percentage of very small particles than the hydraulic nozzles. Given the same amount of turbulence, these fine particles have the potential to stay aloft longer than the larger particles exiting a nozzle. Teske (1995) has demonstrated, in a study of spray drift in downwind canyons, that a portion of the spray from rotary atomizers will stay aloft for great distances. In the Hennigan field studies, the combination of larger particle size and the helicopter downwash (which tends to drive the spray through the canopy) probably resulted in a greater amount of spray from the nozzles penetrating the canopy at each elevation, and falling through to the ground. Indeed, normalized average RI at the canopy top in the full leaf stage is 13% higher for the nozzle spray system (spraying at low volume) than for the Micronairs. RI decreases by 32% from the top of the canopy to the bottom when spraying with nozzles; it decreases by 55% when spraying with the Micronairs. Thus, the finer spray produced by the Micronairs appears to be particularly affected by a denser canopy. The smaller drops, in addition to having an inherently lower impaction efficiency, will also penetrate further into the canopy before settling on an element of foliage, or passing through entirely. This has been observed and reported in coniferous forest studies (Barry, 1984).

The observations made above regarding relative overall effectiveness of helicopter versus fixed-wing spray systems can be summed up with a final observation: although there is high variability in RI for all of the data analyzed in both Hennigan studies, the helicopter spray systems show greater overall effectiveness on the sides of beverage can samplers, at all elevations in the canopy and for all three tree stages, compared to the fixed wing spray systems.

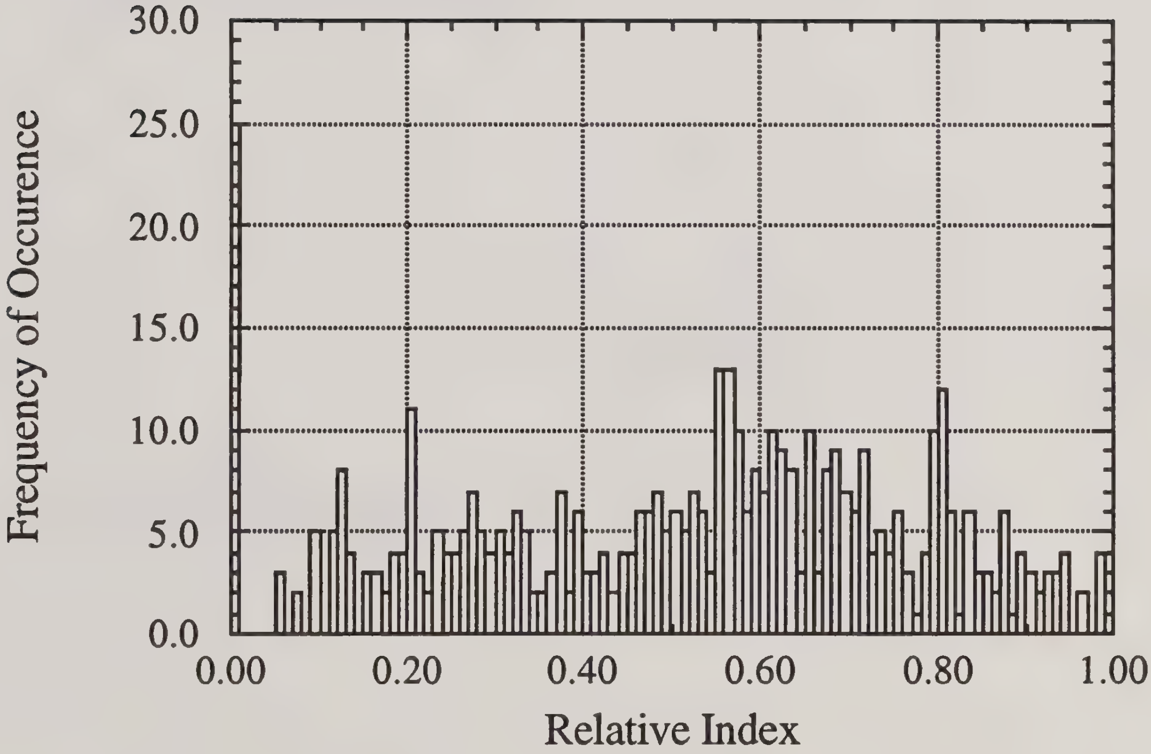



Figure 2: Relative Index (RI) histogram for Hennigan 94 side-of-can sampler data (480 data points).

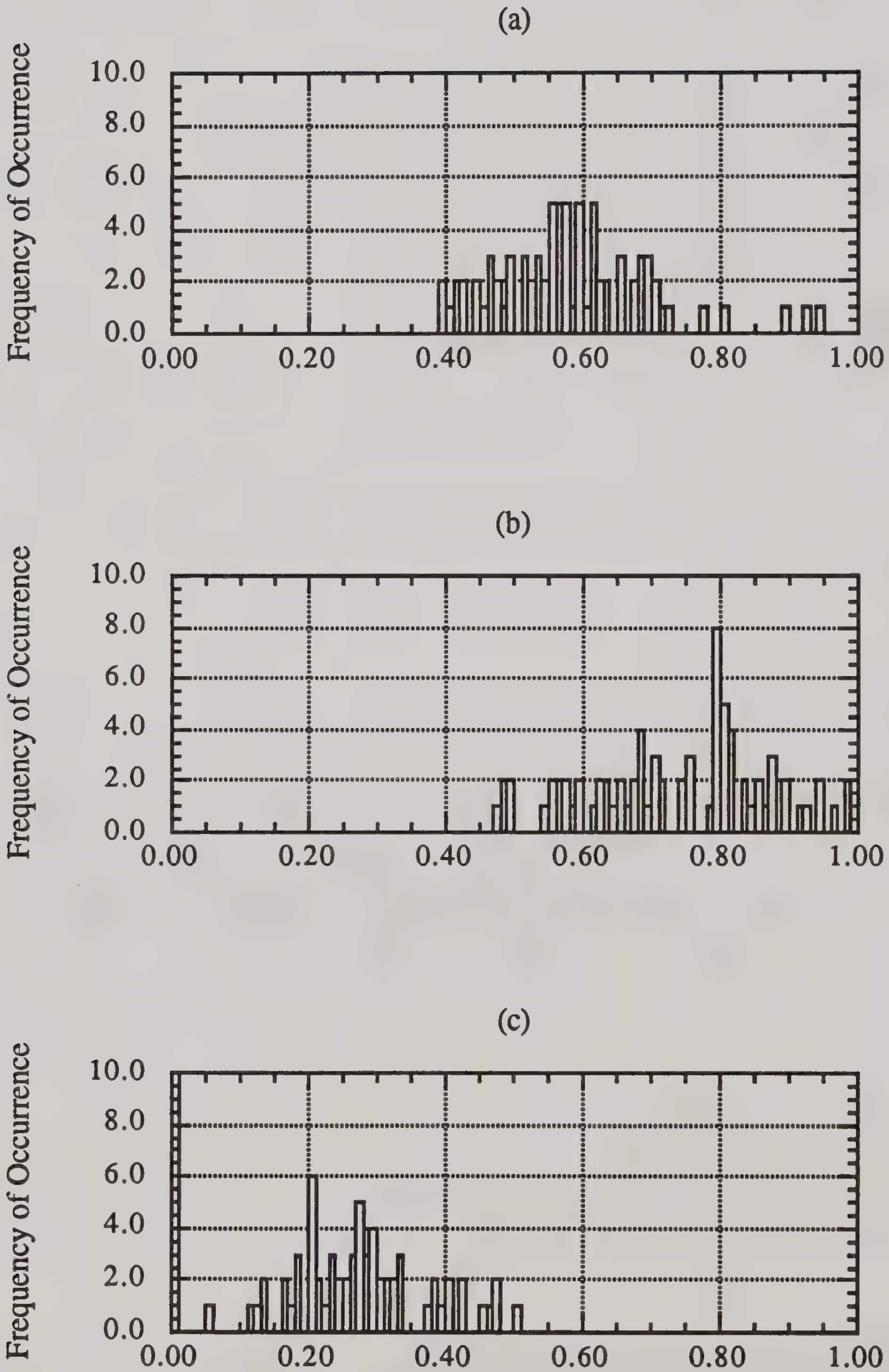



Figure 3: RI histograms for Hennigan 94 side-of-can sampler data, Phase B (a), Phase C (b) and Phase D (c). Trees in popcorn tree stage; 80 data points in each histogram.

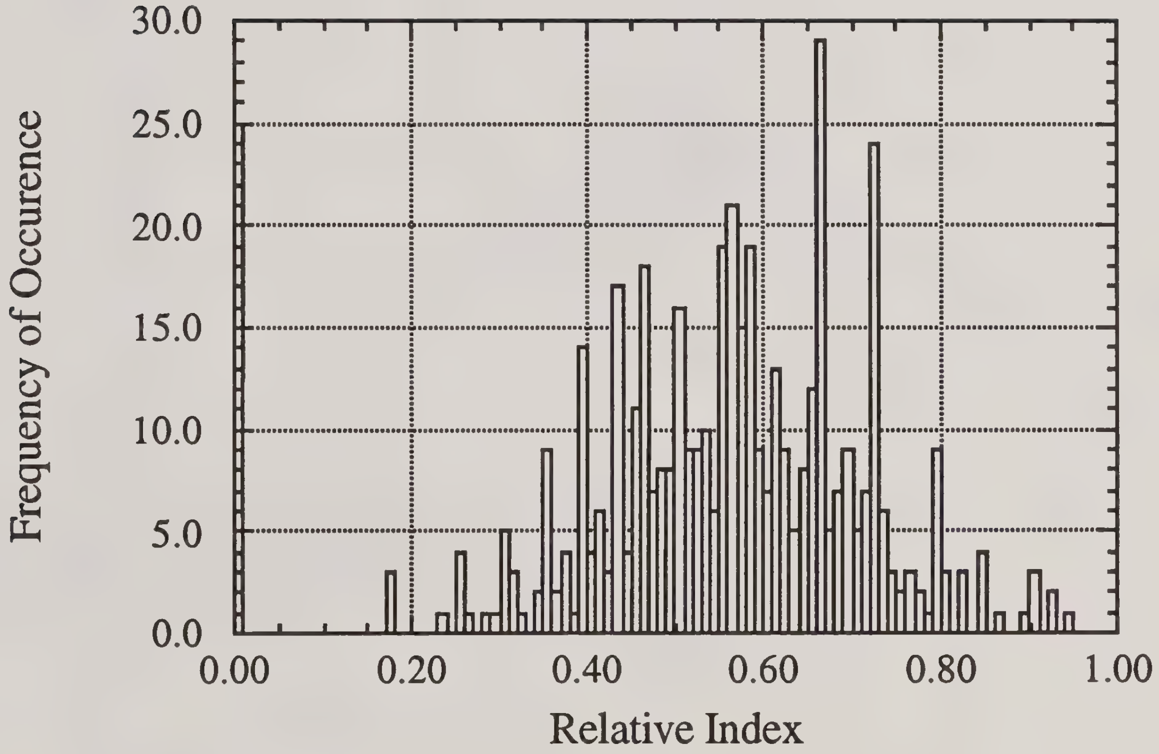



Figure 4: Normalized Relative Index histogram for Hennigan 94 side-of-can sampler data (480 data points).

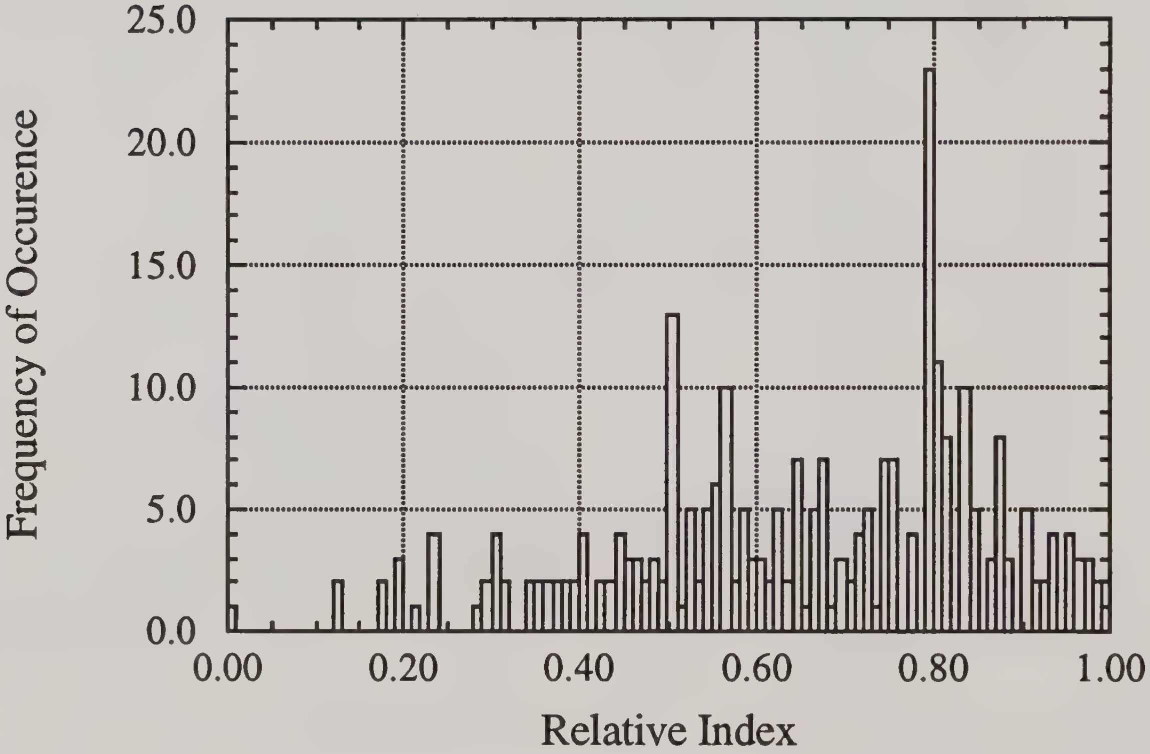
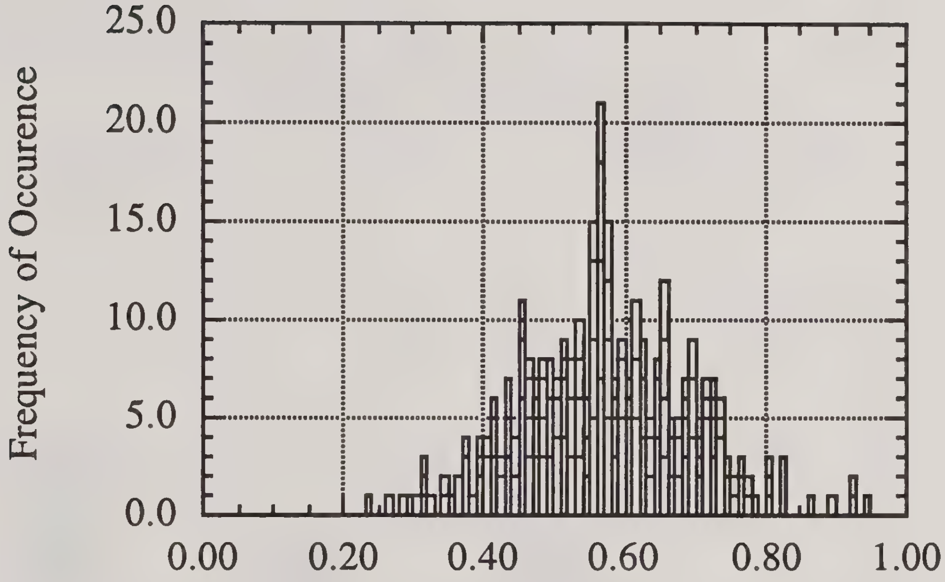



Figure 5: Normalized Relative Index histogram for WIND 85 side-of-can sampler data (320 data points, Phases A and B)

(a)




(b)

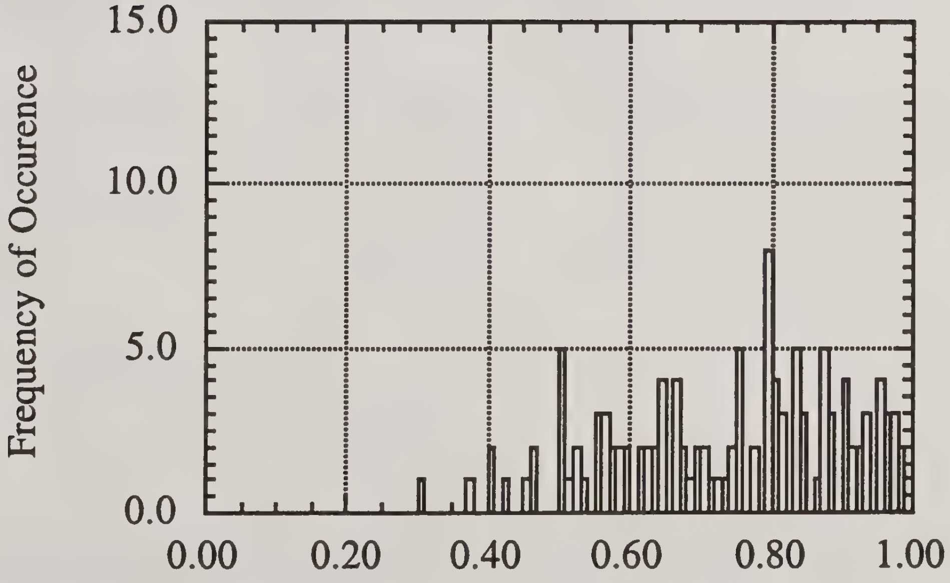



Figure 6: RI histograms for side-of-can sampler data, Hennigan 94 Phases B and C (a), 320 data points; WIND 85 Phase B (b), 160 data points.

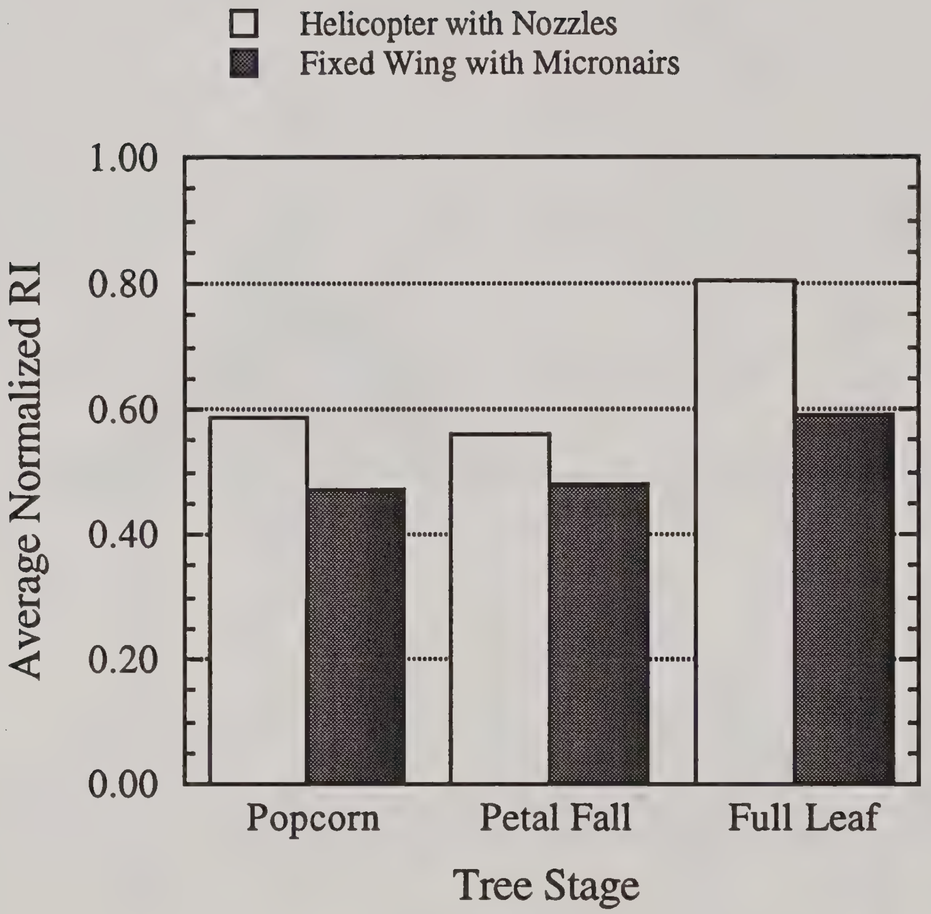



Figure 7: Bar chart of average normalized RI at three stages of flower and foliage, fixed-wing/Micronair spray system versus helicopter/nozzle spray system.

Table 4: Average Normalized RI and Relative Standard Deviation by Tree Stage, for Helicopter and Fixed-Wing Spray Systems

HELICOPTER WITH NOZZLES:

| Test/ Phase | Tree Stage | Average RI (Normalized) | RSD |
|---|---|---|---|
| WIND 85 (June- July) | | | |
| B | Full Leaf | 0.806 | 0.23 |
| C | Full Leaf | 0.954 | -- |
| Hennigan 94 (Feb. 22nd) | | | |
| B+C | Popcorn | 0.586 | 0.20 |
| (March 8th) B+C | Blossom Petal Fall | 0.558 | 0.22 |

FIXED WING WITH MICRONAIR ATOMIZERS:

| Test/ Phase | Tree Stage | Average RI (Normalized) | RSD |
|---|---|---|---|
| WIND 85 (June- July) | | | |
| A | Full Leaf | 0.593 | 0.36 |
| Hennigan 94 (Feb. 22nd) | | | |
| D | Popcorn | 0.471 | 0.56 |
| (March 8th) D | Blossom Petal Fall | 0.482 | 0.53 |

Table 5: Average Normalized RI and Relative Standard Deviation by Elevation for Three Tree Stages, by Spray System

| Test/Phase | Tree Stage | Canopy Elevation | Average RI (Normalized) | RSD |
|---|---|---|---|---|
| HELICOPTER WITH NOZZLES: | | | | |
| WIND 85 | | | | |
| (June - July) | | | | |
| B | Full Leaf | 0.37 | 0.599 | 0.21 |
| | | 0.59 | 0.823 | 0.20 |
| | | 0.78 | 0.924 | 0.13 |
| | | 1.00 | 0.879 | 0.15 |
| C | Full Leaf | 0.37 | 0.829 | -- |
| | | 0.59 | 0.996 | -- |
| | | 0.78 | 1.00 | -- |
| | | 1.00 | 0.991 | -- |
| Hennigan 94 | | | | |
| (Feb. 22nd) | Popcorn | 0.06 | 0.598 | 0.19 |
| B+C | | 0.60 | 0.574 | 0.20 |
| (March 8th) | Blossom | 0.06 | 0.598 | 0.18 |
| B+C | Petal Fall | 0.60 | 0.517 | 0.24 |
| FIXED WING WITH MICRONAIR ATOMIZERS: | | | | |
| WIND 85 | | | | |
| (June - July) | | | | |
| A | Full Leaf | 0.37 | 0.348 | 0.39 |
| | | 0.59 | 0.535 | 0.28 |
| | | 0.78 | 0.711 | 0.16 |
| | | 1.00 | 0.777 | 0.15 |
| Hennigan 94 | | | | |
| (Feb. 22nd) | Popcorn | 0.06 | 0.490 | 0.53 |
| D | | 0.60 | 0.453 | 0.58 |
| (March 8th) | Blossom | 0.06 | 0.464 | 0.55 |
| D | Petal Fall | 0.60 | 0.490 | 0.50 |

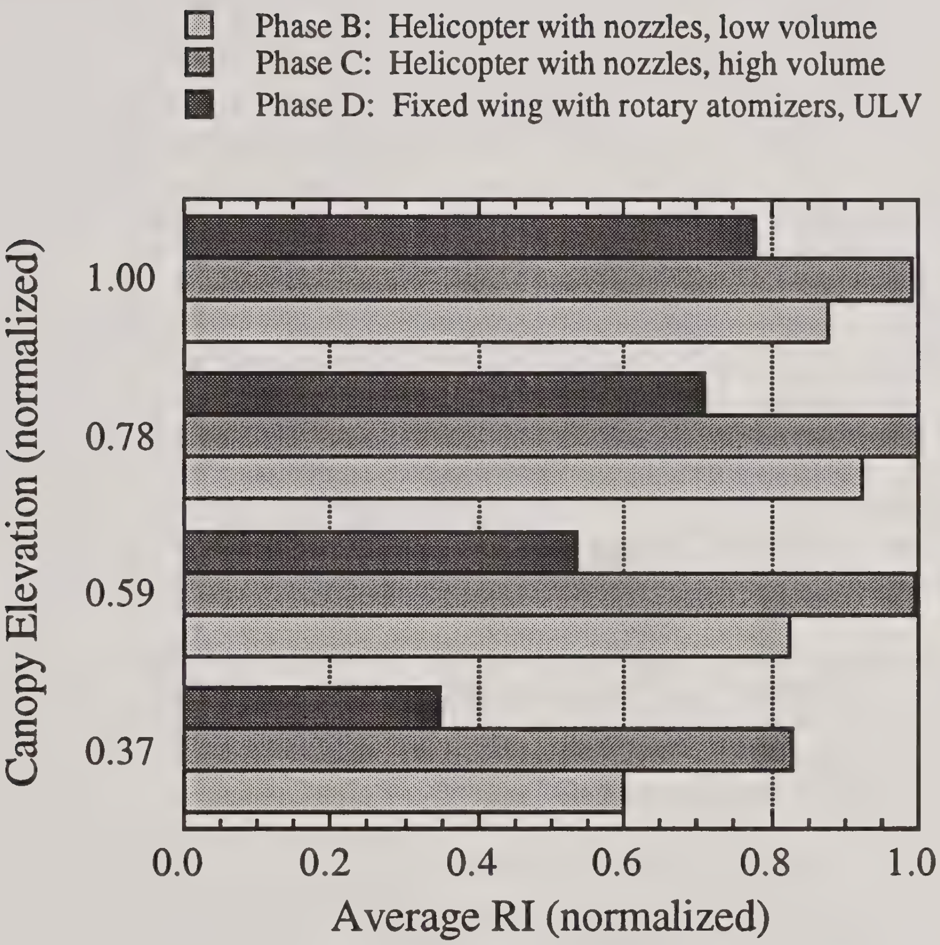



Figure 8: Average normalized RI at four elevations in a full leaf almond canopy, side-of-can samplers, for a hydraulic nozzle spray system at two application rates (low and high volume) and a rotary atomizer system (ULV).

## 5. Top-of-Can Deposition Compared to RI

In the previous section, normalized values of RI were used to evaluate overall effectiveness on the sides of can samplers at different elevations in the Hennigan studies, for three stages of flower and foliage and for two spray systems. In this section, (un-normalized) RI values will be compared with top-of-can drop deposition data.

Table 6 shows the average RI of each phase of WIND 85 and Hennigan 94, calculated using the original value of $N_B$ (20 drops per square centimeter). Whereas the normalized average RI values were meant to minimize the effects of different flow rates on the RI calculation, the values shown here give an indication of the overall effectiveness due to volume of material sprayed.

It is readily apparent from Table 6 that the fixed-wing spray system with Micronairs spraying ULV (0.5 gal/acre) shows the least overall effectiveness on the sides of the can samplers. As previously mentioned, many of the sampler segments counted showed no deposition at all, and drop counts for the remaining segments were generally very low. An average RI below 0.35 indicates that there were no sampler segments for which there was 100% overall effectiveness by the assumed measure of 20 drops per square centimeter (see Table 3); in fact, an average below 0.25 indicates that those drops which were counted were also not distributed uniformly around the samplers.

Micronairs spraying at low volume over a full leaf canopy (WIND 85 Phase A) show much better overall effectiveness than those spraying at ULV. However, a helicopter-based nozzle spray system at the same volume of application over the same type of canopy shows much better overall effectiveness (average RI = 0.57 for the Micronairs and average RI = 0.78 for the nozzles).

It is worth noting that the average RI for each phase of the Hennigan 94 study is nearly the same in each stage of canopy, popcorn and blossom petal fall, even when flow rate is not normalized. It appears that, for the spray systems tested, there is little difference in canopy effect on spray penetration between these two tree stages.

WIND 85 Phase B and Hennigan 94 Phase B were both conducted with a helicopter spraying with nozzles at low volume. The average RI for WIND 85 Phase B is much higher than that of Hennigan 94 Phase B; the difference in overall effectiveness may be due to the difference in nozzle type and placement (WIND 85 used 28 D2-45 T-Jet nozzles while Hennigan 94 used 20 CP plastic nozzles), or to the different canopies. Time of day and meteorological conditions were also much different.

As previously noted, WIND 85 Phase C was sprayed at such high volume that the foliage was oversaturated, and the numbers of drops counted on sampler segments were so high that, using the assumed 20 drops per square centimeter as a base count, the RI for every sampler location in this phase was 1.0. Newton et al. (1989) state that the canopy's spray collection efficiency was probably overwhelmed by runoff, and that at the bottom of the canopy only 40% of the spray was observed; even so, there were still well over 20 drops per segment.

Deposition data from the top-of-can samplers used in both field studies is also available, and is presented in Tables 6 and 7. Table 6 presents the average deposition of drops on top-of-can samplers for each phase, in drops per square centimeter. Assuming the same level of effectiveness on top-of-can samplers as on the side segments, Table 6 shows that all helicopter phases of WIND 85 and Hennigan 94 achieved 100% average overall effectiveness on the tops of the cans, based on the criteria of 20 drops per square centimeter. The fixed-wing phases of the field studies achieved 100% average effectiveness on the tops of cans when spraying at low volume (WIND 85 Phase A) but only 30% and 25% average effectiveness when spraying ULV (Hennigan 94 Phase D, popcorn and blossom petal fall, respectively).

There is not much difference in the average number of drops deposited on the top-of-can samplers by the helicopter spray system in different tree stages: about the same average number of drops were deposited during the blossom petal fall stage as during the popcorn stage. The Micronair atomizers also deposited about the same average number of drops on the top-of-can samplers during these two tree stages. It is interesting to note that, while average effectiveness on the tops of can samplers for all helicopter treatments and the low-volume Micronair treatment were higher than the RI on their sides, for the two ULV Micronair treatments the average effectiveness on top was almost the same as RI on the side! This suggests that the small drops from the ULV treatments were moving at an angle and impacted with energy generated by the aircraft wake, resulting in more uniform deposition around the entire can.

Table 7 presents the average number of drops counted at each canopy elevation in both field studies, by phase. It is apparent from this table that the basic trends with canopy elevation seen in the side-of-can data are true for the top-of-can data as well. For the full leaf canopy (the WIND 85 trials), the average number of drops deposited on top of the cans decreases as the spray passes through the canopy. However, the top-of-can samplers appear to show more impact of canopy effects at each successive elevation than the side-of-can samplers. Figure 9 shows average RI for the top-of-can samplers at four elevations in the full leaf canopy, for the hydraulic nozzle spray system spraying at low volume and the rotary atomizer system at ULV. The hydraulic nozzle system at high volume is not shown, since deposition at all elevations above the bottom of the canopy was very high due to oversaturation.

For the other two tree stages (popcorn and blossom petal fall), there are no data at the top or bottom of the canopy. Although there is much more of a difference between the mid-canopy and ground elevation top-of-can drop deposition than there is in the side-of-can drop deposition, for each type of application (helicopter low volume, helicopter high volume, and fixed wing ULV), average levels of top-of-can drop deposition at each elevation are similar for both tree stages. Side-of-can RI values are similar throughout the canopy, and are almost the same for these two tree stages.

There are at least two issues involved in the evaluation of top-of-can drop deposition at elevations within the canopy: the collection efficiency of the can samplers and the impaction efficiency of the drops. The collection efficiency of the top-of-can samplers is higher than the collection efficiency of the side-of-can samplers (May and Clifford, 1967). The top-of-can samplers are square as opposed to cylindrical, and are more directly in the path of the spray droplets. Although drops are traveling vertically (down) and

horizontally (sideways), their path is predominantly downward. Thus, greater numbers of drops are expected on the top-of-can samplers for all phases except WIND 85 Phase C (oversaturation of the foliage and runoff, resulting in nearly complete coverage of all portions of the samplers). As mentioned in the previous section, the overall impaction efficiency of the spray decreases as it passes through the canopy (larger drops impact first). This is clearly seen in the progressive decrease in average number of drops counted on the top-of-can samplers as the spray passes through the canopy (Table 7 and Figure 9), and also has been reported by other researchers. Because the remaining drops are smaller than the drops which have already impacted, they are more susceptible to turbulence within the canopy and thus will either settle more uniformly all over the can or follow the airflow around the can to pass through the canopy.

The top-of-can samplers from the ULV treatment with Micronair atomizers (Hennigan 94 Phase D) show much less deposition than the top-of-can samplers from the low volume Micronair treatment (WIND 85 Phase A). Thus, both the side-of-can and top-of-can overall effectiveness for Hennigan 94 Phase D is clearly much worse than any of the other applications in the two studies. However, the top-of-can deposition during the low volume Micronair treatment (WIND 85 Phase A) was comparable to the top-of-can deposition during the low volume nozzle treatment (WIND 85 Phase B) in the same stage canopy. This seems to indicate that, at low volume, the Micronair spray system tested provides similar coverage on the top of a foliage element, and somewhat less effective coverage on the sides of the element, than the hydraulic nozzle spray system.

It is also interesting to note that at the mid-canopy elevation, overall effectiveness on the top-of-can samplers is similar for the two types of nozzle spray systems used on helicopters (T-Jet for WIND 85 and CP for Hennigan 94), and at the three tree stages. The average top-of-can deposition for Hennigan 94 Phase B (low volume application with CP nozzles) is 24 drops per square centimeter in the popcorn stage and 23 drops per square centimeter in the blossom petal fall stage, and for WIND 85 Phase B the average is 31 drops per square centimeter (low volume application with T-Jet nozzles). Overall effectiveness, according to the 20 drops per square centimeter criteria, is similar for all three tree stages. This further supports the observation made in the previous section that the overall effectiveness of helicopter spray systems seems to be independent of nozzle type.

Table 6: Side-of Can Average RI and Top-of-Can Deposition for Each Phase of the Hennigan 94 and the WIND 85 Studies

| Test/ Phase | Stage of Flower/ Foliage | Aircraft and Spray System | Application Rate[1] (gal/acre) | Average RI[2] (Side-of-Can) | Average Top-of-Can Deposition (drops/sq cm) |
|---|---|---|---|---|---|
| WIND 85 | Full Leaf | | | | |
| A | | Ag Cat / Micronairs | 4.0 (low) | 0.566 | 50 |
| B | | Hiller 12E/ Nozzles | 4.0 (low) | 0.777 | 52 |
| C | | Hiller 12E/ Nozzles | 30.0 (high) | 1.00 | 295 |
| Hennigan 94 | Popcorn | | | | |
| B | | Bell 206 / Nozzles | 5.0 (low) | 0.584 | 20 |
| C | | Bell 206 / Nozzles | 15.0 (high) | 0.745 | 50 |
| D | | Ag Cat / Micronairs | 0.5 (ULV) | 0.223 | 6 |
| Hennigan 94 | Blossom Petal Fall | | | | |
| B | | Bell 206 / Nozzles | 5.0 (low) | 0.560 | 20 |
| C | | Bell 206 / Nozzles | 15.0 (high) | 0.777 | 47 |
| D | | Ag Cat / Micronairs | 0.5 (ULV) | 0.201 | 5 |

1. Refers to low volume, high volume, or ULV (Ultra Low Volume).

2. All RI calculations are done with a base drop count $N_B = 20$. This is the number of drops per square centimeter of foliage element for which 100% biological effectiveness is assumed.

Table 7: Top-of-Can Average Drop Deposition by Elevation and Phase of Treatment, for Three Tree Stages

| Test/ Phase | Tree Stage | Canopy Elevation | Average Top-of-Can Deposition (drops/cm²) |
|---|---|---|---|
| HELICOPTER WITH NOZZLES: | | | |
| WIND 85 | | | |
| (June - July) | | | |
| B | Full Leaf | 0.37 | 16 |
| | | 0.59 | 31 |
| | | 0.78 | 72 |
| | | 1.00 | 88 |
| C | Full Leaf | 0.37 | 134 |
| | | 0.59 | 344 |
| | | 0.78 | 354 |
| | | 1.00 | 349 |
| Hennigan 94 | | | |
| (Feb. 22nd) | Popcorn | 0.06 | 28 |
| B+C | | 0.60 | 42 |
| (March 8th) | Blossom | 0.06 | 29 |
| B+C | Petal Fall | 0.60 | 37 |
| FIXED WING WITH MICRONAIR ATOMIZERS: | | | |
| WIND 85 | | | |
| (June - July) | | | |
| A | Full Leaf | 0.37 | 11 |
| | | 0.59 | 18 |
| | | 0.78 | 57 |
| | | 1.00 | 104 |
| Hennigan 94 | | | |
| (Feb. 22nd) | Popcorn | 0.06 | 5 |
| D | | 0.60 | 6 |
| (March 8th) | Blossom | 0.06 | 4 |
| D | Petal Fall | 0.60 | 6 |

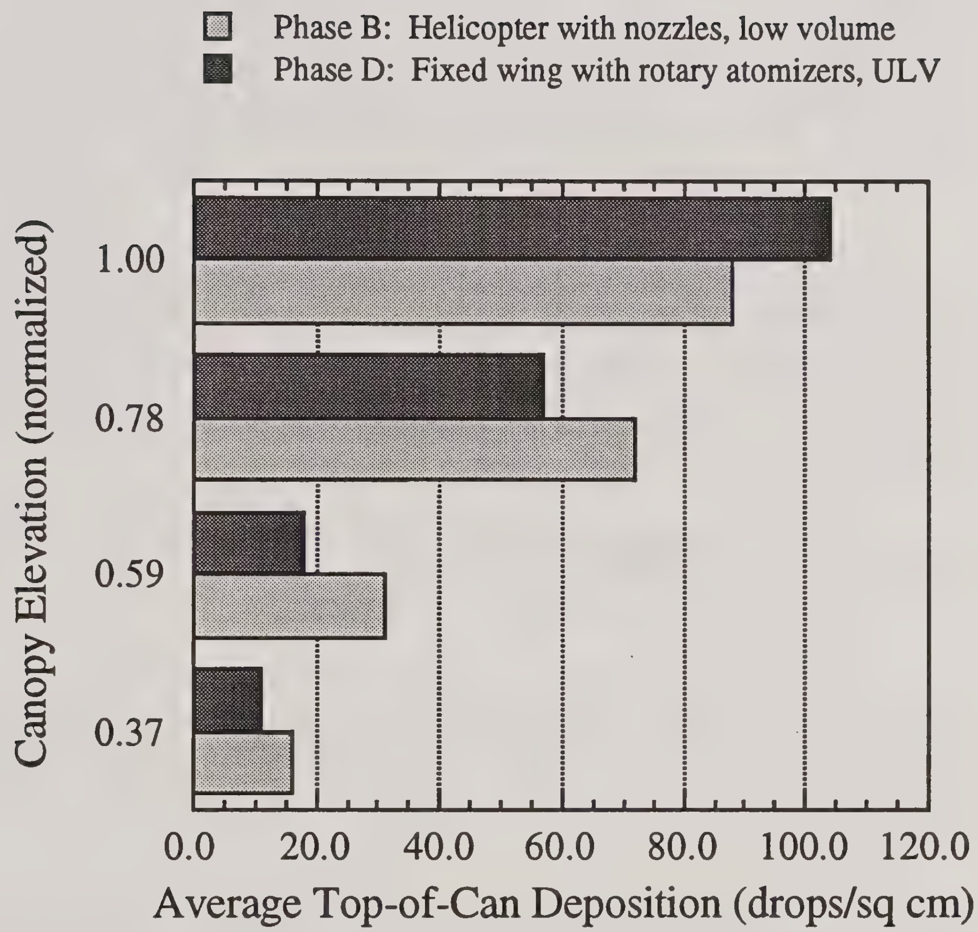



Figure 9: Average canopy penetration (in drops per square centimeter) at four elevations in a full leaf almond canopy, for a hydraulic nozzle spray system at low volume and a rotary atomizer system at ULV.

## 6. Summary of Results

Many observations have been made in this report regarding the overall effectiveness of the spray systems tested in the Hennigan studies, and the applicability of the RI (Relative Index) formulation. They may be summarized as follows:

1. As defined in section 3, RI does a good job of correlating side-of-can drop deposition data from various spray systems and at different canopy elevations. When RI calculations are normalized to the same flow rate, data from both Hennigan studies show consistent trends.

2. Normalized average RI for all phases of WIND 85 and Hennigan 94 are normally distributed, indicating that samplers in these studies were well-placed to model canopy effects. Replications were consistent for WIND 85 (160 sampler positions in each phase) and Hennigan 94 (80 sampler positions for each phase on each day of testing), indicating that fewer well-placed samplers could have been used to give an effective model of the canopy.

3. The normal distributions also indicate that the RI calculation is independent of sampler location with respect to tree centerline (i.e., east versus west of the tree) and of the aircraft flight line.

4. The RSD (Relative Standard Deviation) of normalized average RI for a fixed-wing spray system (Micronair atomizers) is much higher than that for a helicopter spray system (nozzles). Thus, although there is high variability in RI for all the data analyzed, the Micronairs show much more variability in side-of-can coverage than do the nozzles.

5. Normalized average RI for all applications by helicopter (i.e., for different nozzle spray systems) are similar at each canopy height, as is the RSD of the normalized average, indicating that the overall effectiveness of helicopter applications on side-of-can samplers is independent of nozzle type.

6. Comparing the two spray systems at the same application rate (low volume), the nozzles show 36% higher normalized average RI than the Micronair atomizers in a full leaf canopy. The helicopter spray system shows greater overall effectiveness at all elevations and in all canopy stages.

7. Without normalizing to the same flow rate, the helicopter spray systems tested at Hennigan applied spray more uniformly at each tree stage than did the fixed-wing spray system. In the full-leaf canopy, the high-volume helicopter application (WIND 85 Phase C) achieved complete coverage of the entire canopy, but oversaturated the foliage to the point of runoff. The low-volume helicopter application (WIND 85 Phase B) achieved high RI throughout the canopy and 100% average effectiveness on the top-of-can samplers as well.

8. For the helicopter applications, side-of-can data showed similar overall effectiveness for all flow rates, regardless of nozzle type, at all tree stages. Top-of-can sampler data at mid-canopy showed similar coverage when the canopy was in the blossom petal fall stage and the popcorn stage, and more coverage in the full leaf stage than in either bloom stage.

9. Finally, data from side-of-can samplers and top-of-can samplers clearly show that overall effectiveness of the Micronair spray system at ULV is much worse than overall effectiveness of the other spray systems tested. However, for the Micronairs at ULV, the overall effectiveness for top-of-can data and side-of-can data is similar, indicating similar coverage all over the sampler.

10. The most striking difference in both side-of-can RI calculations and top-of-can drop deposition data is that the Micronair atomizers, particularly when spraying at ULV, deposit fewer drops per square centimeter of sampler area, and deposit with less uniformity around the side of the beverage can, than do the hydraulic nozzle spray systems evaluated here. This is probably due to the fine spray produced by atomizers, which has greater potential for drift, low impaction efficiency and penetrates deeper into the canopy (or passes all the way through) before settling.

## 7. Conclusions

When evaluating the effectiveness of spray penetrating a canopy during aerial application, it is necessary to examine not only the amount of drops deposited on elements of foliage, but also the uniformity of coverage over their surface. We have developed a useful tool for determining the overall effectiveness from the side surface of a beverage can sampler: the Relative Index (RI). The RI for a side-of-can sampler gives overall effectiveness on a scale of 0 to 1.0, where 1.0 indicates 100% effectiveness over the entire sampler. RI combines the coverage effectiveness and the biological effectiveness by incorporating a base drop count, which, in this report, is assumed to be 20 drops per square centimeter. The base drop count is a biological indicator, dependent on the type of pesticide applied and on the type of pest to be controlled. Biological effectiveness is an important aspect of overall effectiveness of spray coverage, and thus of RI. To accurately represent the overall effectiveness of a field study, the base drop counts for various formulations relative to insect pests and other undesirable species must be defined, either through field testing or in the laboratory.

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